



F&U som støtte for innovation og konkurrencedygtighed

Madsen, Peter Hauge; Buhl, Thomas

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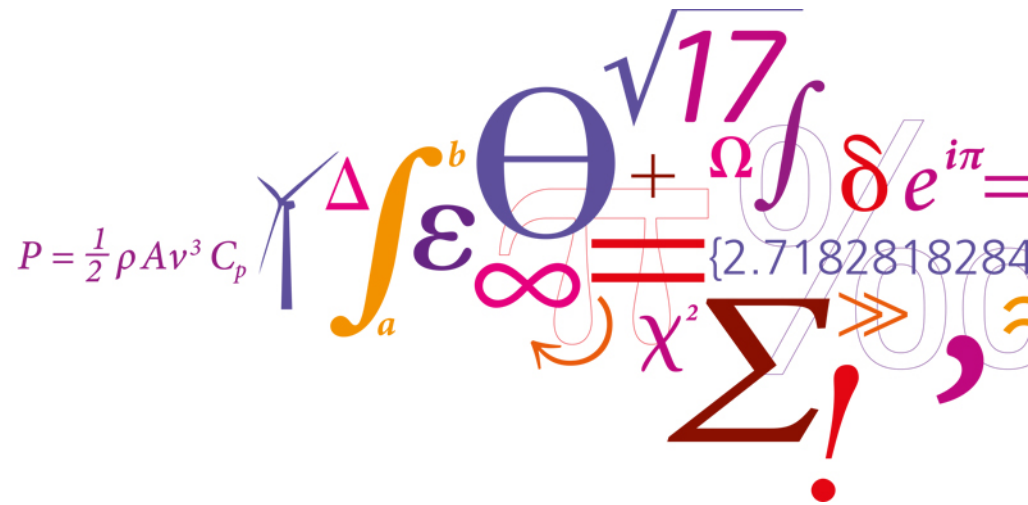
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F&U som støtte for innovation og konkurrencedygtighed

Peter Hauge Madsen & Thomas Buhl
Institut for Vindenergi, DTU

Offshoreenergy.dk's årsmøde
23. og 24. oktober 2014 i Odense



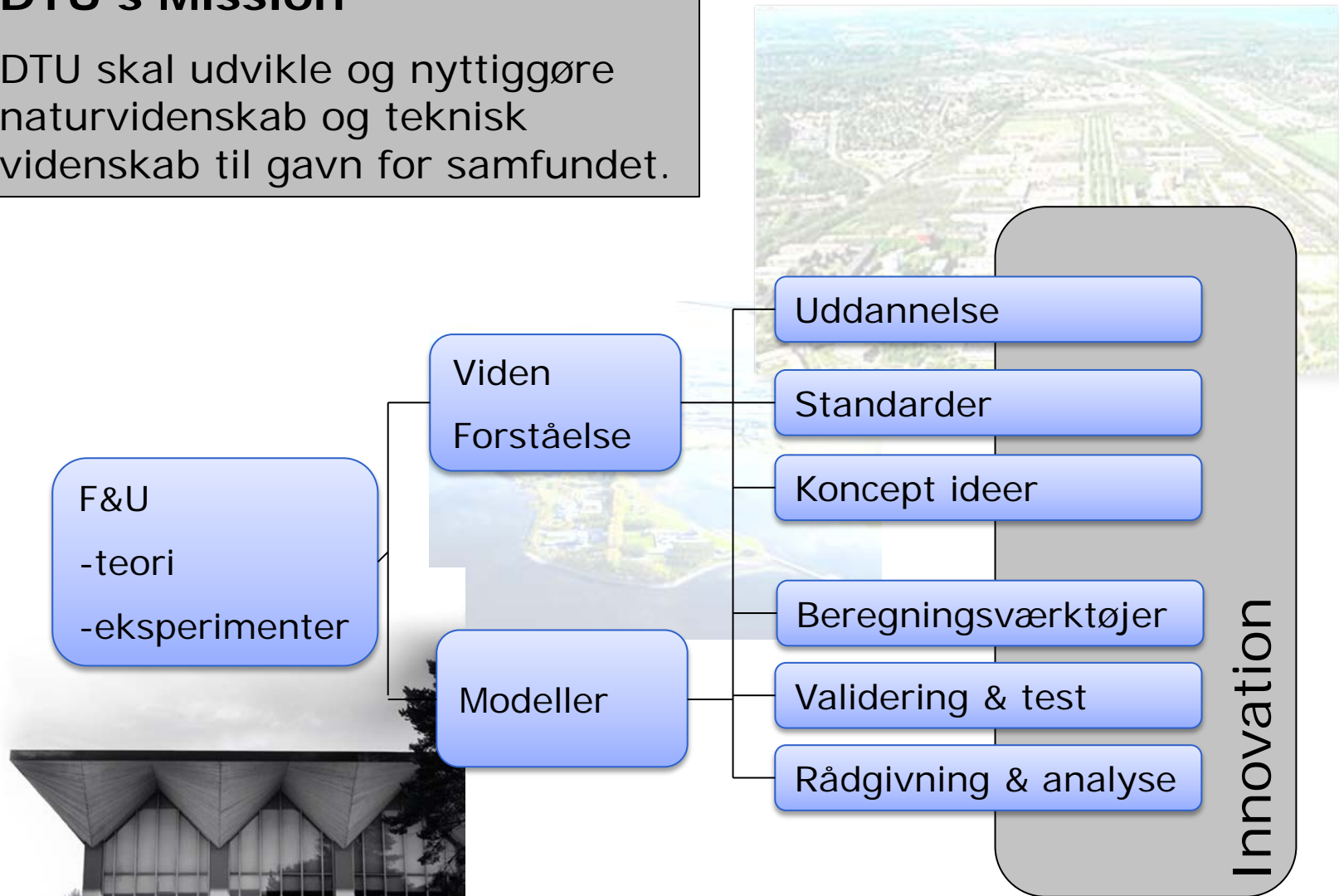
DTU's Mission

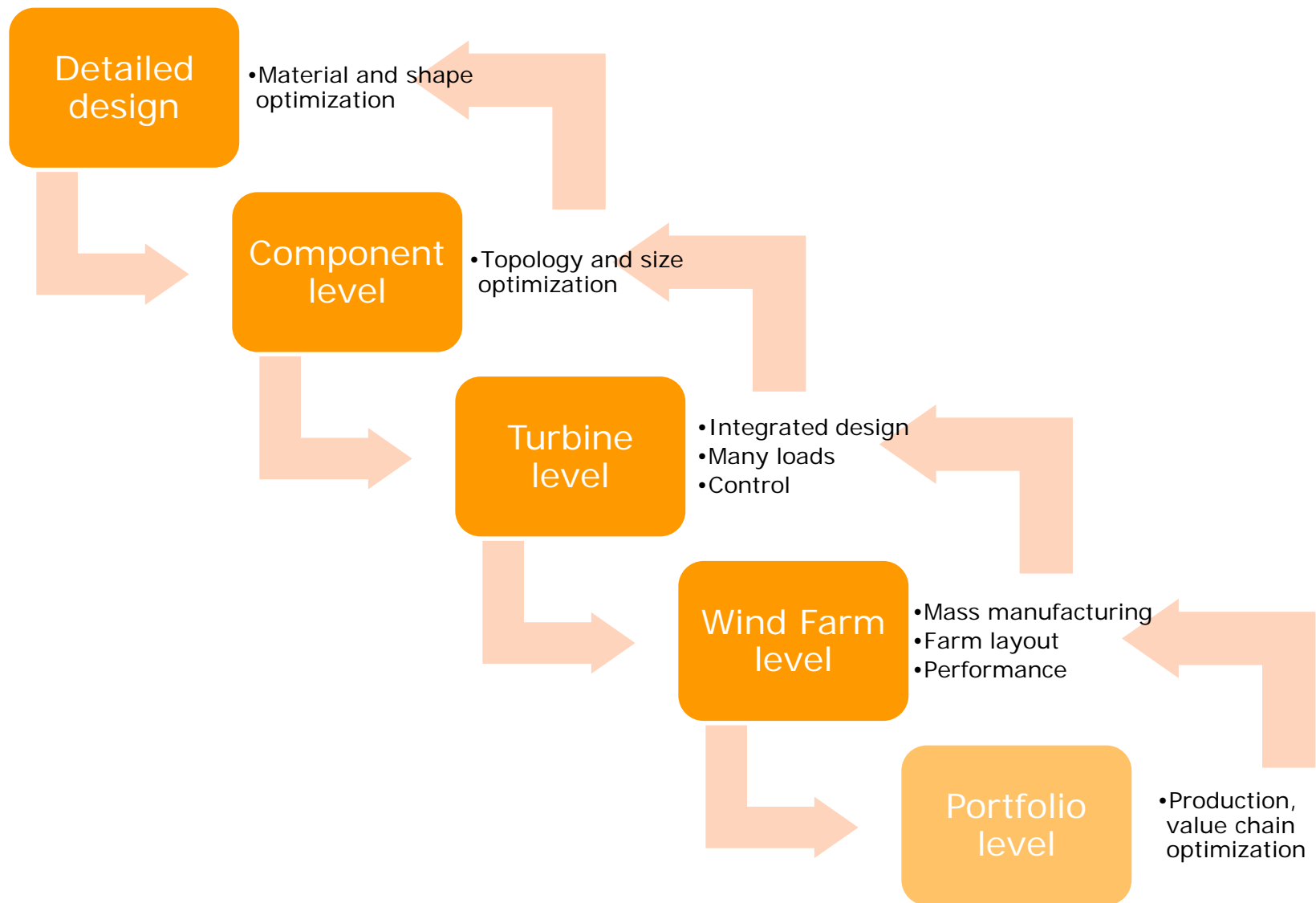
DTU skal udvikle og nyttiggøre naturvidenskab og teknisk videnskab til gavn for samfundet.

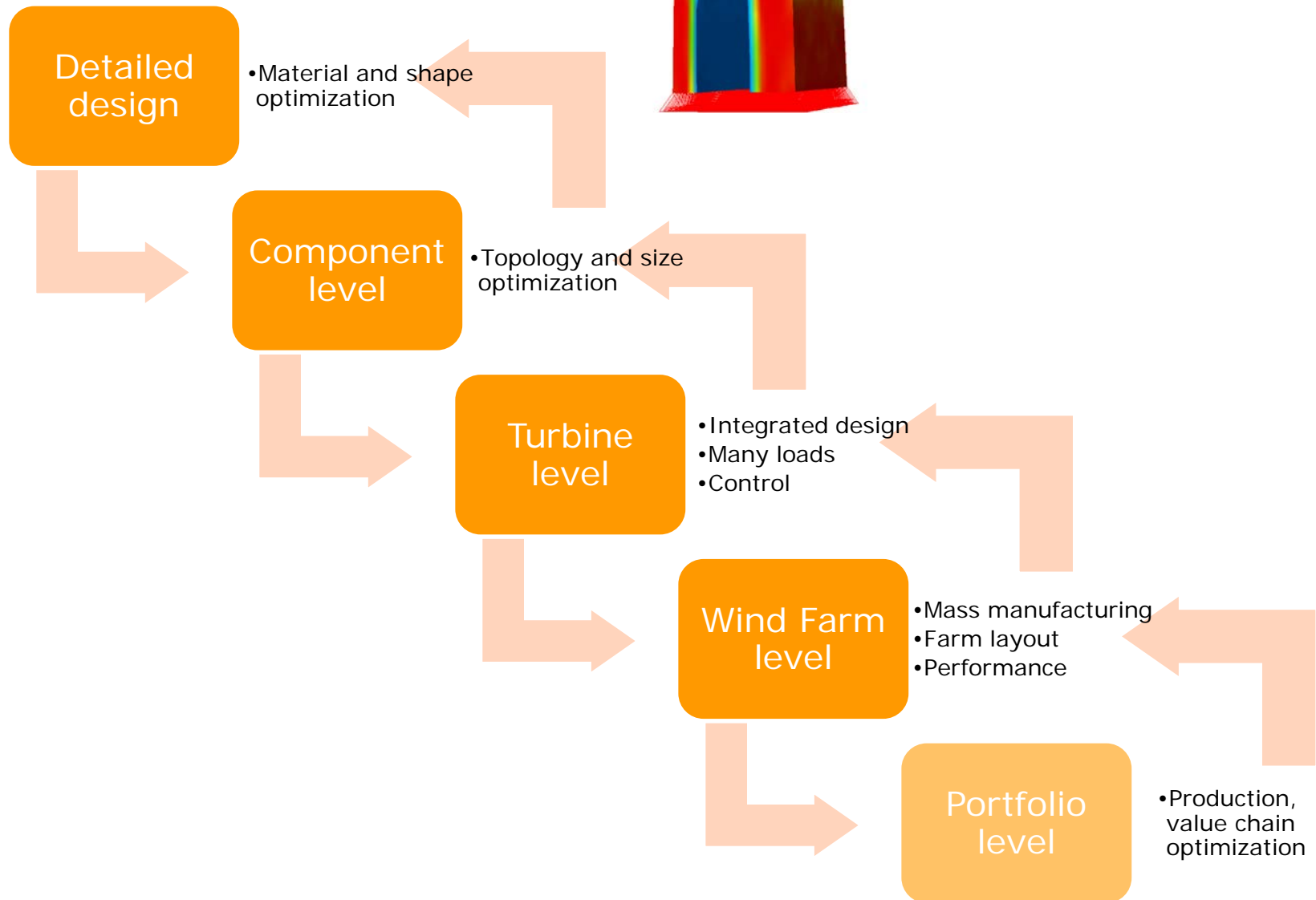
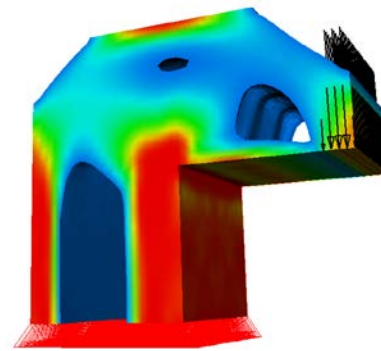


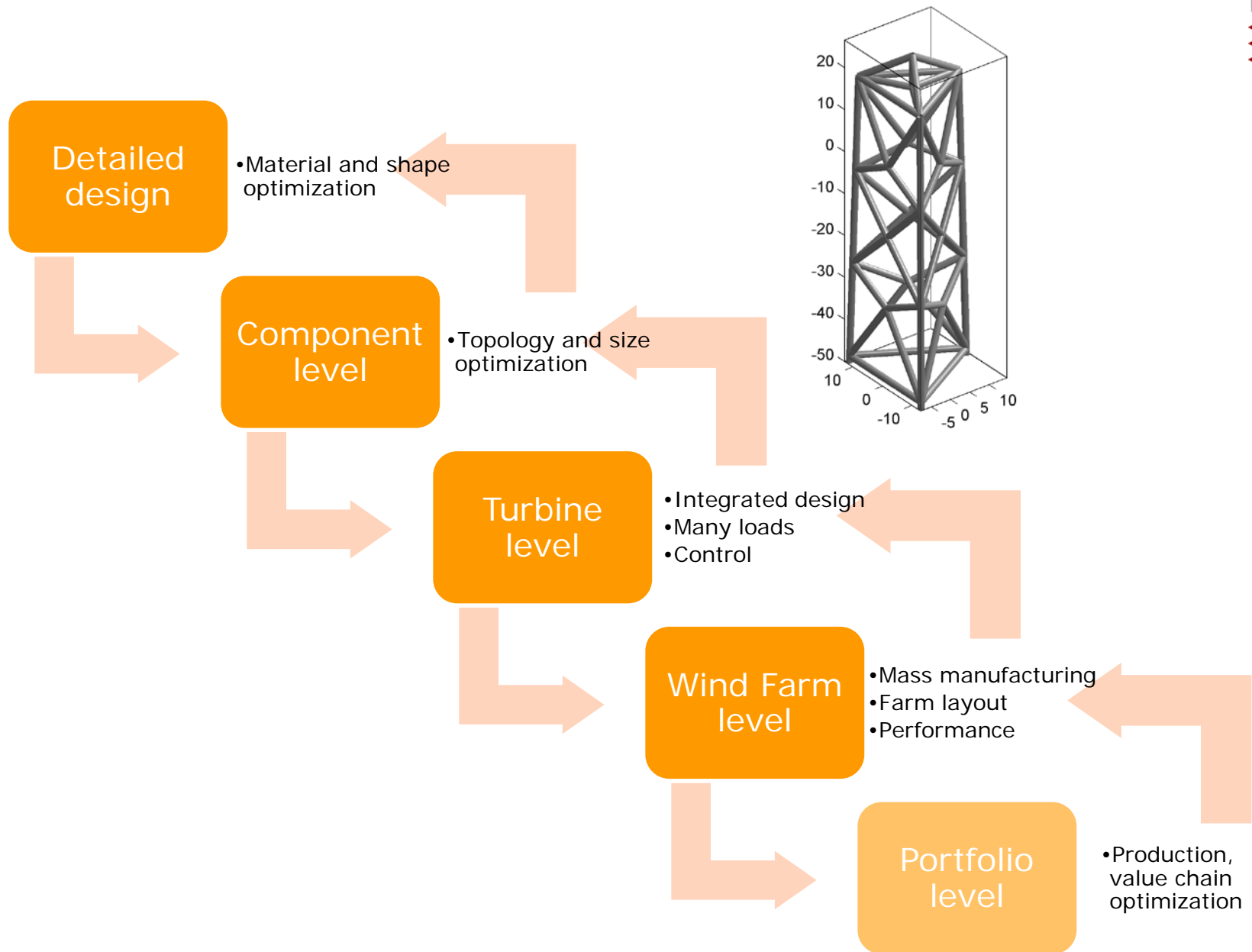
DTU's Mission

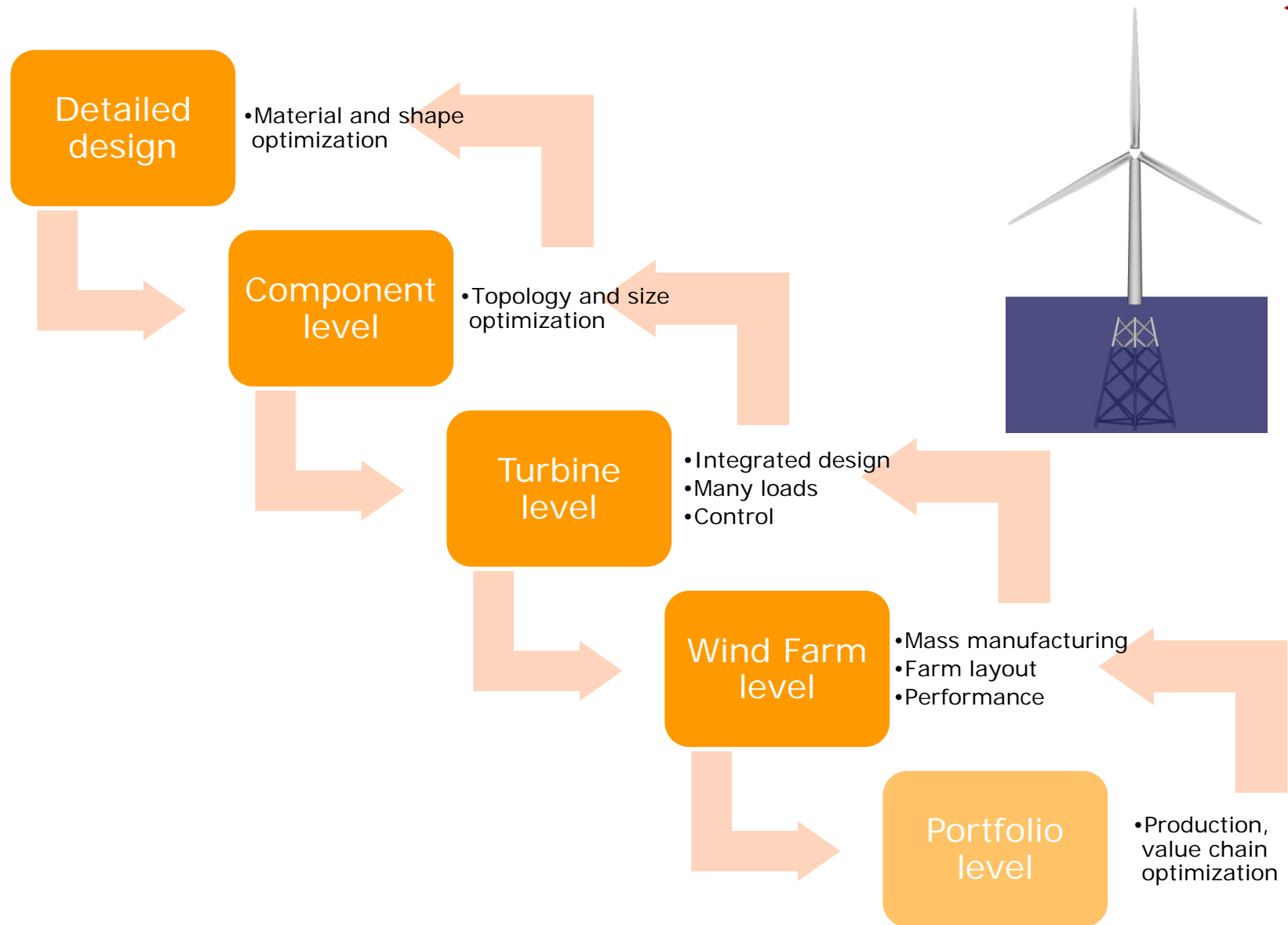
DTU skal udvikle og nyttiggøre naturvidenskab og teknisk videnskab til gavn for samfundet.

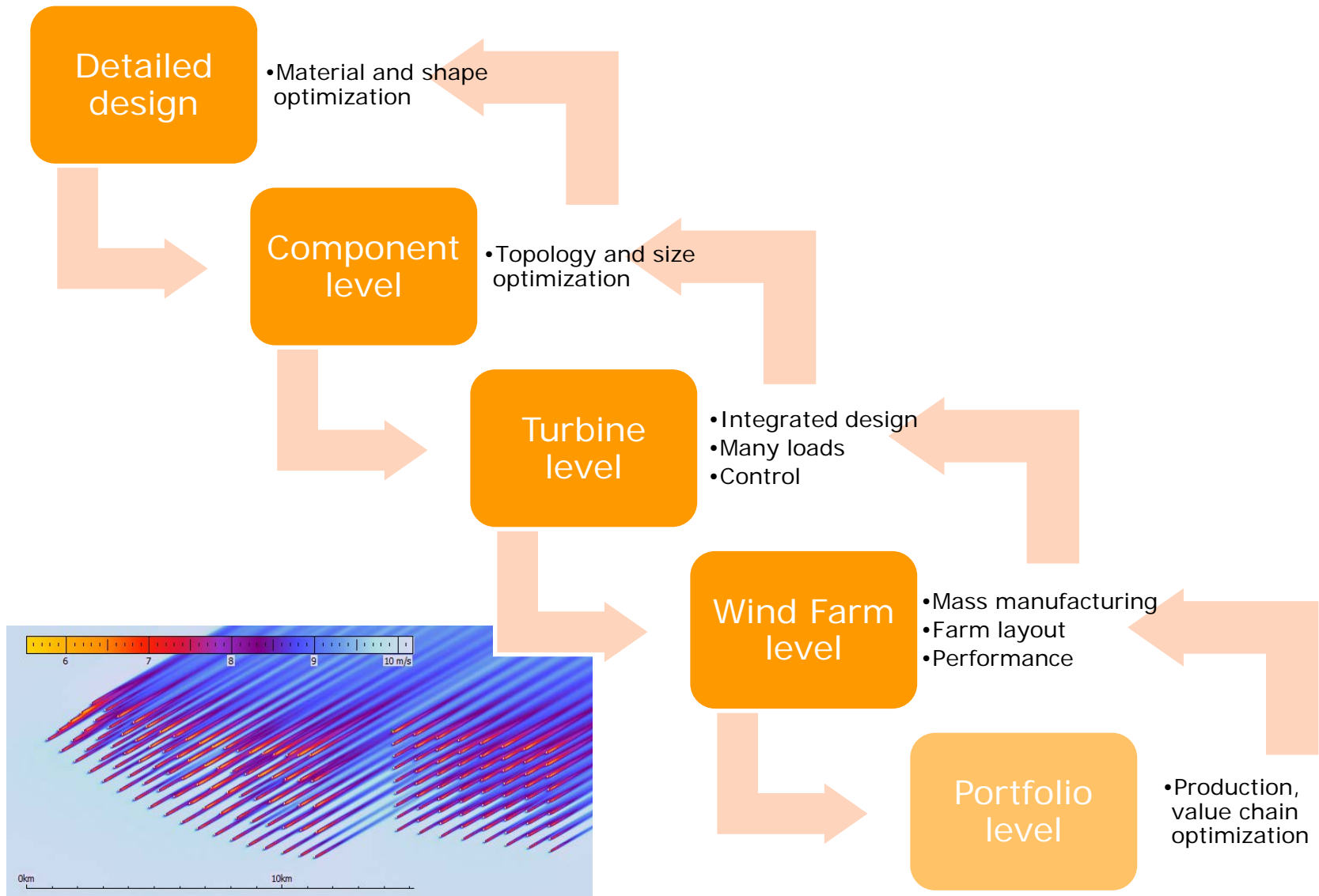


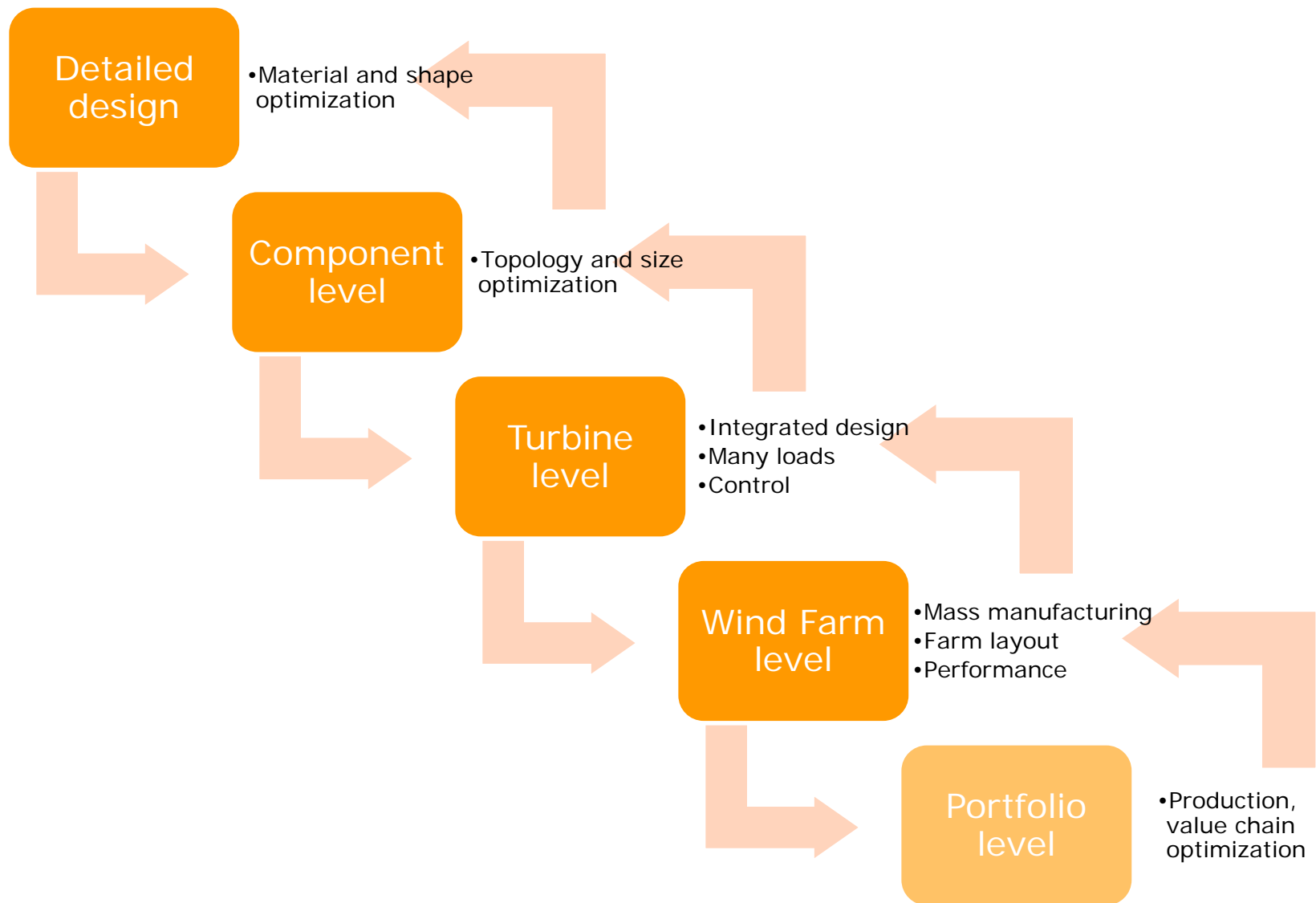













FP7 project – Design Tool for Offshore Wind Farm Clusters



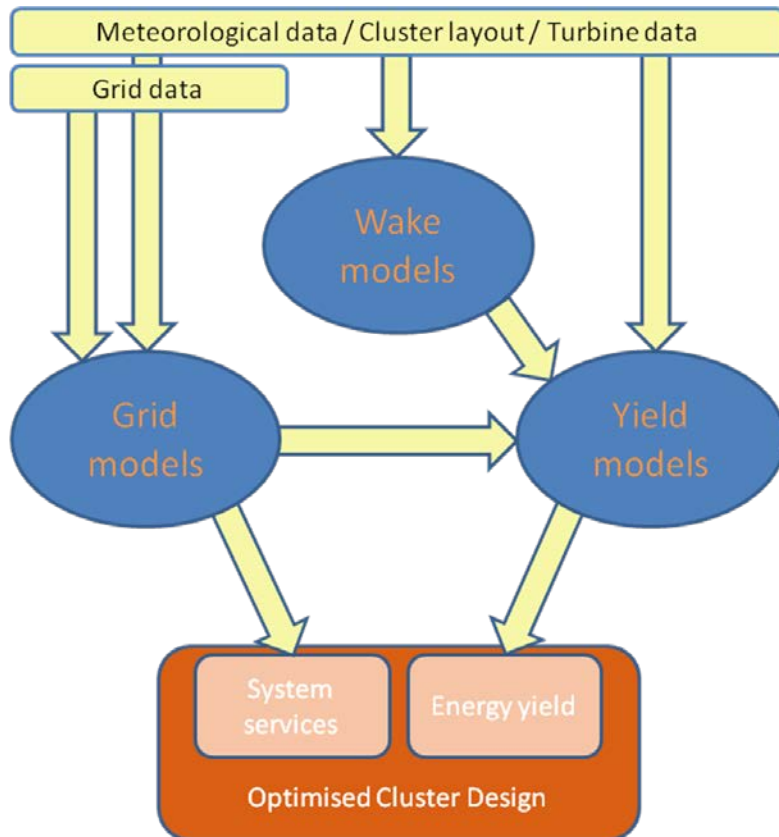
A robust, efficient, easy to use and flexible tool created to facilitate the optimised design of individual and clusters of offshore wind farms

© SIEMENS PRESS PHOTO

Progress is to achieve a robust design tool for planning of offshore wind farms. The progress include benchmark analysis of several wake models using production data, investigation on some uncertainties on annual energy production and study of inter- and intra-array grid possibilities for the offshore.



EERA DTOC concept

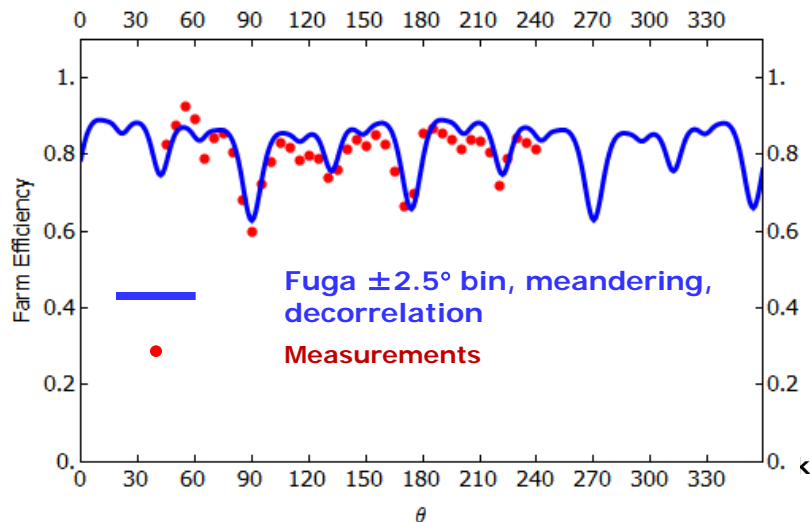
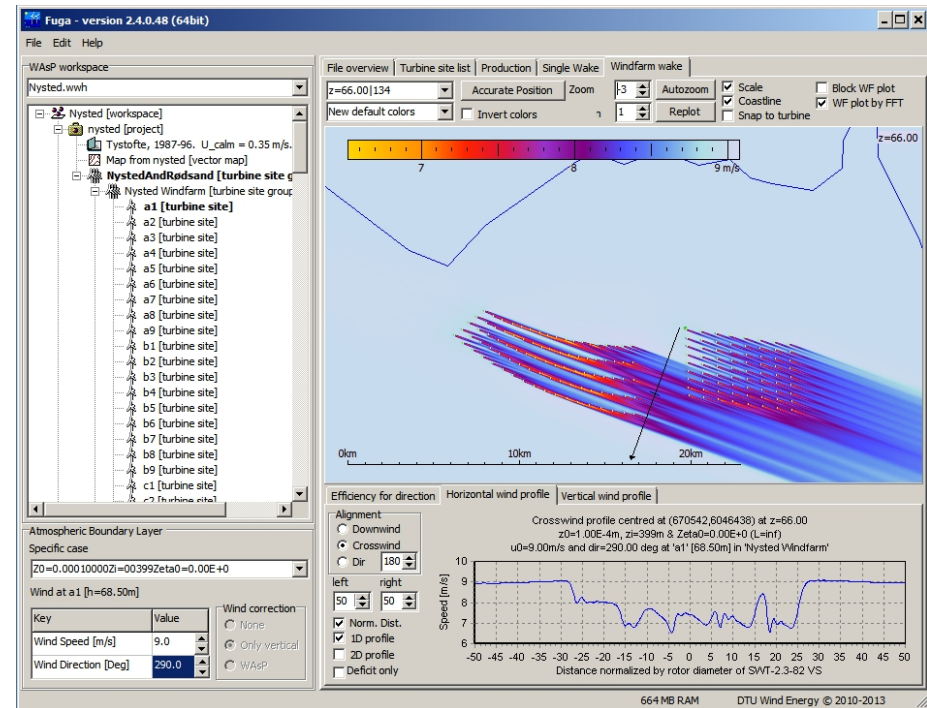


Main Components

- Use and bring together existing models from the partners
- Develop open interfaces between them
- Implement a shell to integrate
- Fine-tune the wake models using dedicated measurements
- Validate final tool

Fuga – wake model for large offshore windfarms

- Solves linearized RANS equations
- Latest version incorporates: atmospheric stability, meandering, effects of non-stationarity and spatial de-correlation of the flow field.
- No computational grid, no numerical diffusion, no spurious pressure gradients
- Integration with WAsP: import of wind climate and turbine data.
- Fast, mixed-spectral solver:
 - 10^6 times faster than conventional RANS!
 - 10^8 to 10^{10} times faster than LES!



Hornsrev validation

* Søren Ott, Jacob Berg and Morten Nielsen: 'Linearised CFD Models for Wakes', Risoe-R-1772(EN), 2011

EERA DTOC portfolio of models

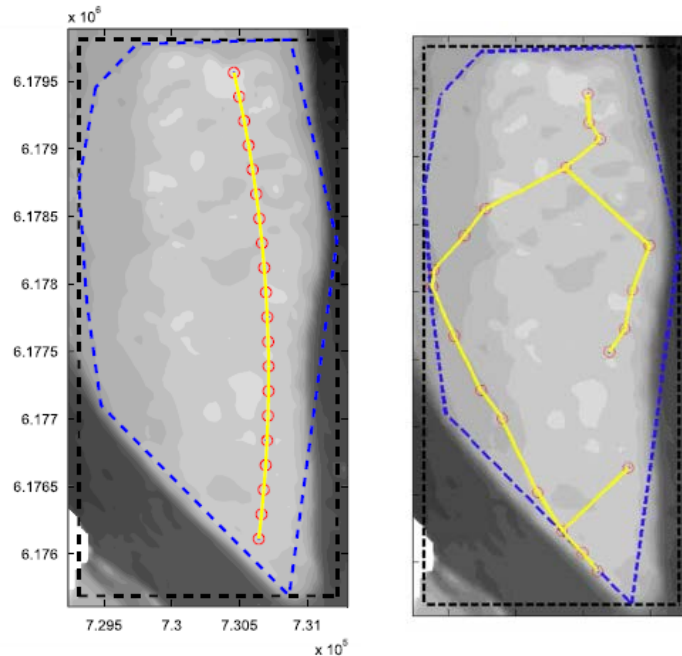
Name	Partner	Status	Programs	Input/ output	Script/ GUI	Database interface	IPR	Com
CFDWake	CENER		Fluent, C++, OpenFOAM	ASCII	script	Yes		
CorWind	Risoe DTU	Ope	DOS exe Delphi	CSV files	no	no	+	+
CRES-farm	CRES	Ope	Linux/ Fortran77	ASCII	no	no	+	
CRES--flowNS	CRES	Ope	Linux/ Fortran77	ASCII	no	no		
DWM	Risoe DTU	Ope	Fortran, pc, pc- cluster	ASCII	script		+	
ECNS	ECN	Beta	Linux/ Fortran90	ASCII	No	No	+	
EeFarm	ECN	Alpha	Matlab	Matlab scripts	Script/ GUI	yes	+	+
Farm-farm interaction	ECN	Ope	Fortran	ASCII	No	no	+	
FarmFlow	ECN	Ope	Delphi	ASCII/ binary	GUI	Yes	+	+
FlowARSM	CRES	Alpha	Linux/ Fortran77	ASCII	no	no		
FUGA	Risoe DTU	Ope	Fortran, C, Delphi, pc	ASCII	Script/ GUI	No	+	
NET-OP	SINTEF	Proto type	Matlab	ASCII	script	No	+	
Skiron/WAM	CENER	Ope	Unix/ Fortran	GRIB	script	yes		
TOPFARM	Risoe DTU	Beta	Matlab/C/ Fortran	ASCII	script		+	
UAEP	Risoe DTU		Matlab, pc	ASCII/ binary	no	yes		
VENTOS	UPorto	Beta	Unix/ Fortran	ASCII	no	yes	+	+
WAsP	Risoe DTU	Ope	Windows pc	ASCII	Script/ GUI	No	+	+
WCMS	Fraunhofer	Ope	Matlab/JAVA	OracleDB		yes	+	
WRF	Risoe DTU	Ope	Unix, Linux, Fortran90	netCDF	Shell script	yes		
WRF/ROMS	CIEMAT	Ope	Linux/ Fortran	netCDF	script	yes	+	

TOPFARM

TOPFARM is a fundamentally new approach to layout optimization of wind farms. From the investor's perspective the TOPFARM platform answers the fundamental question:

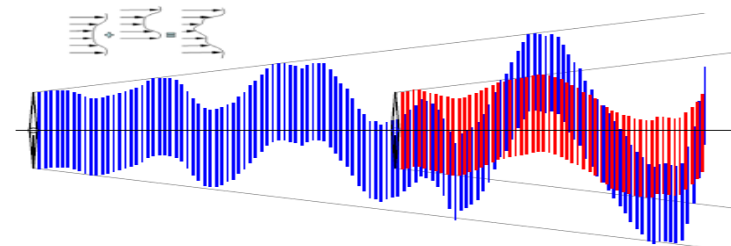
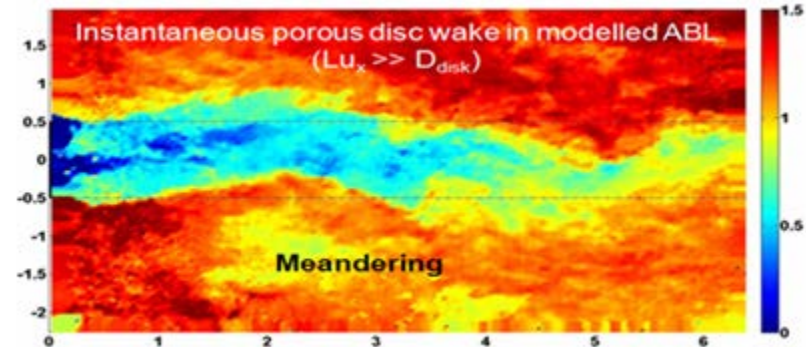
"What kind of layout results in the optimal economical performance of the wind farm throughout its lifetime".

The balance between power, loads and costs



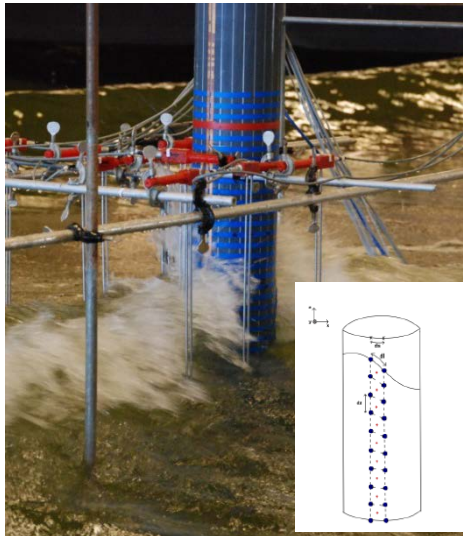
Middelgrunden layout as of now and as results of the TOPFARM optimization.

Measurement of deficit in atm. boundary layer wind tunnel

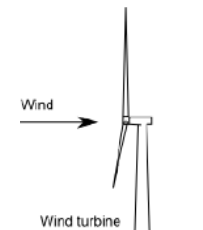
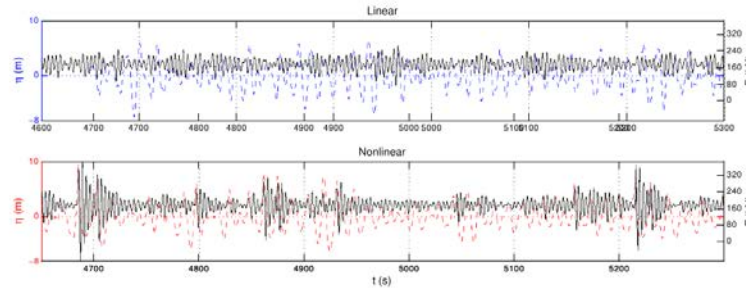


Wake meandering assumption in DWM

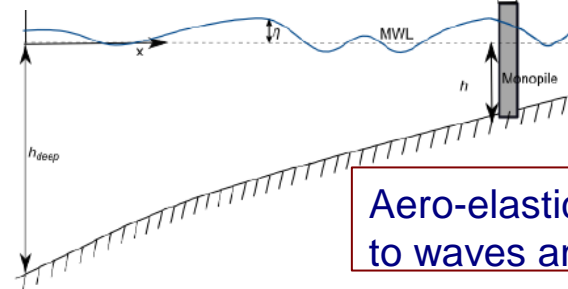
Wind-wave loads and response for offshore wind turbines



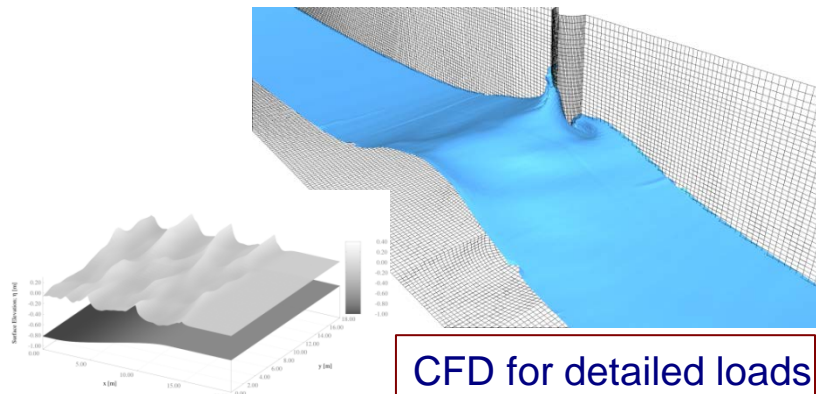
Load models for highly nonlinear waves



Dynamics of floating wind turbines



Aero-elastic response to waves and wind

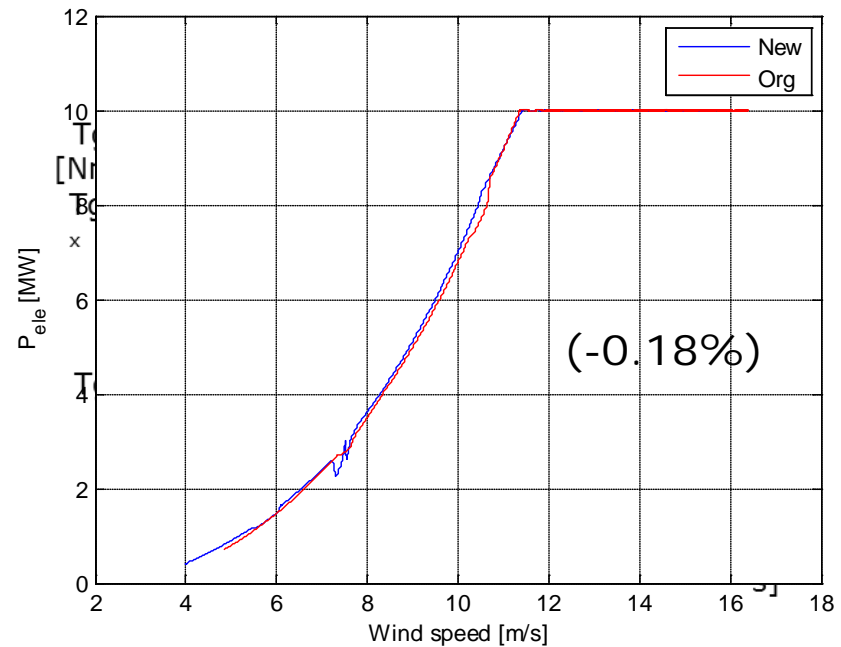
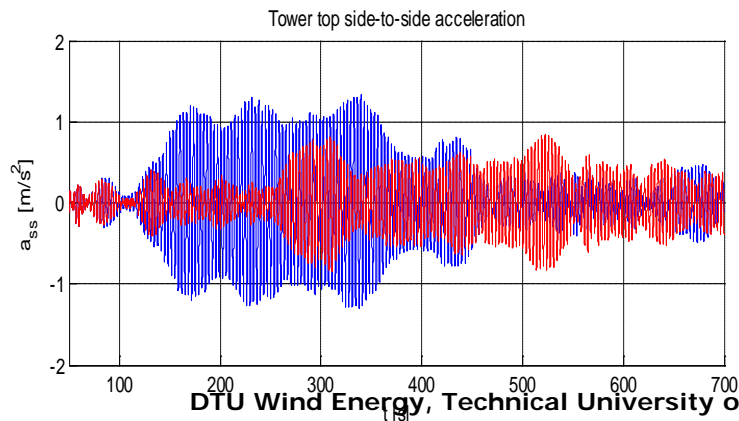
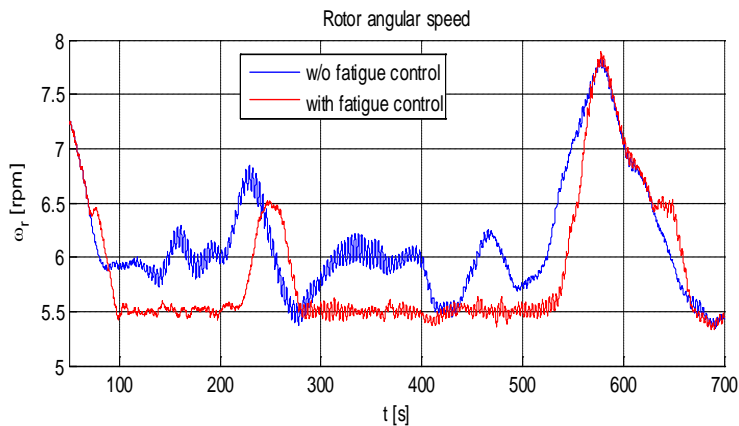


CFD for detailed loads

Offshore wind turbine control system

- **Power production**

- Generator torque control
- Collective pitch control

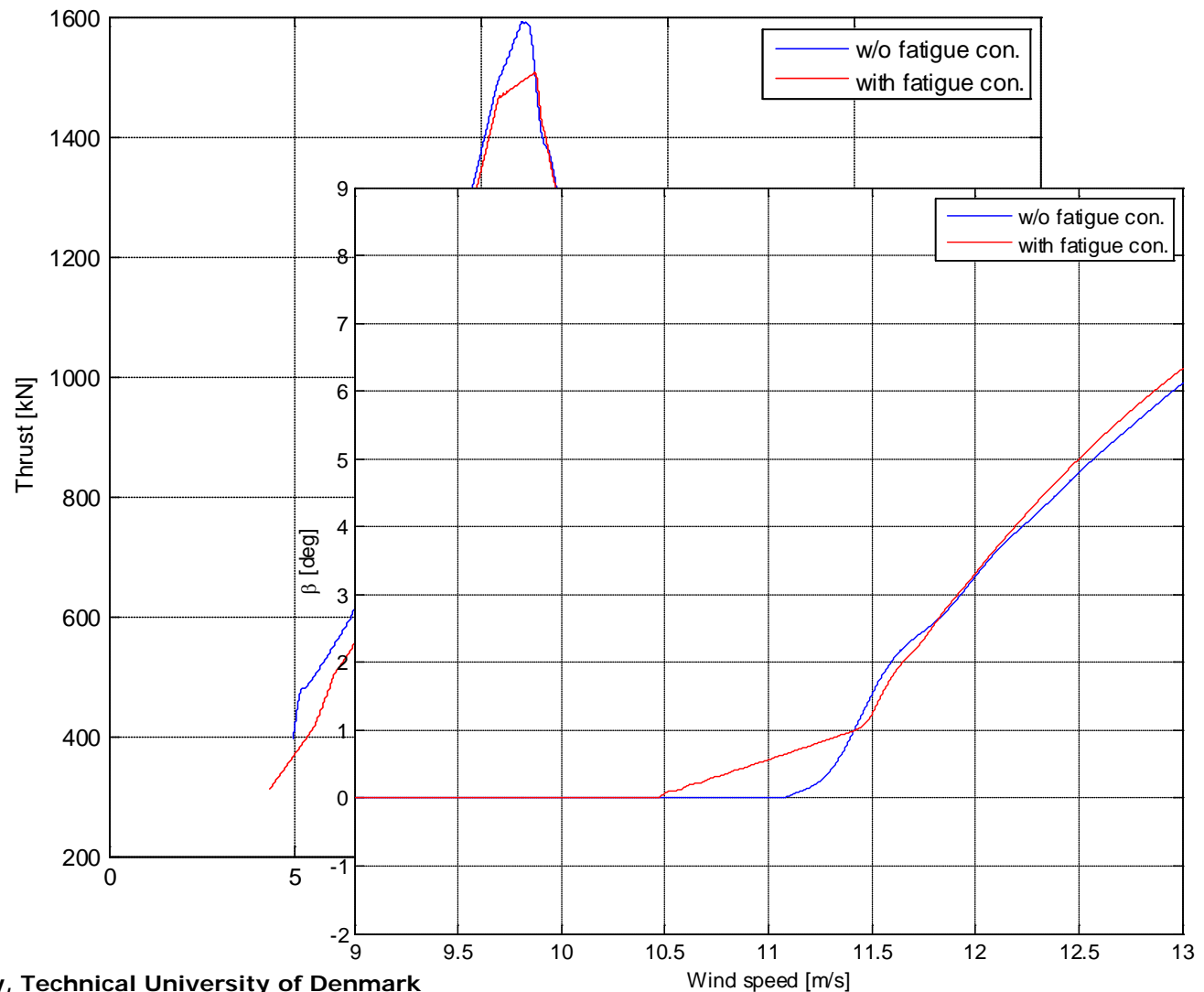
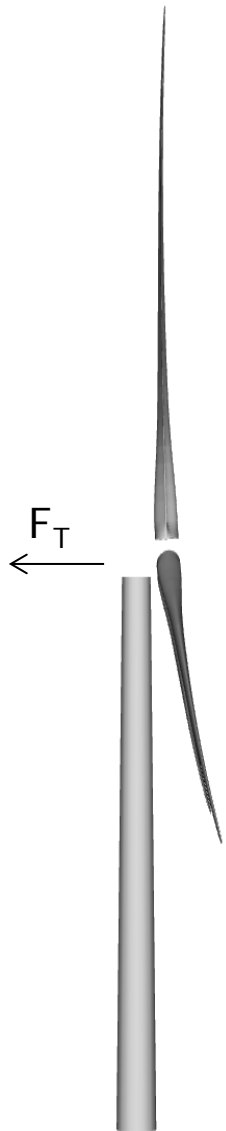


- **Extreme and fatigue load reduction**

- Drive train damper (T_G)
- Exclusion zone (T_G)
- Tower fore-aft mode damper (CPC)
- Thrust peak shaver (CPC)

Collective pitch control

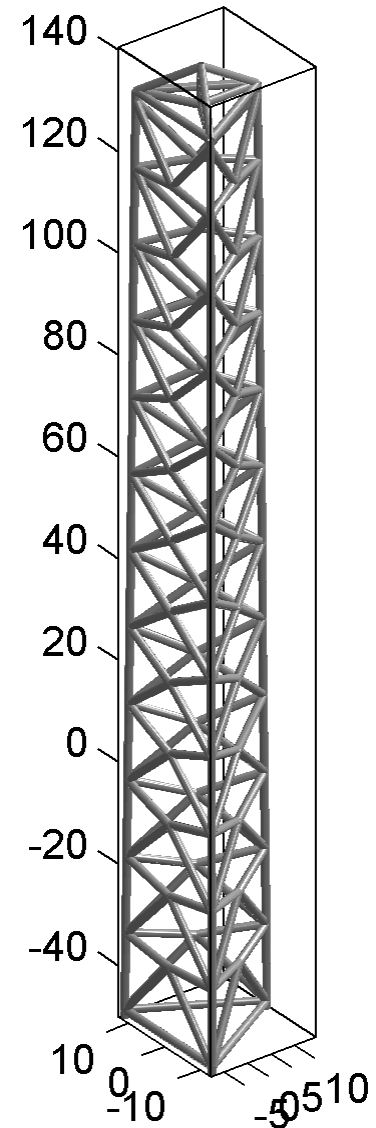
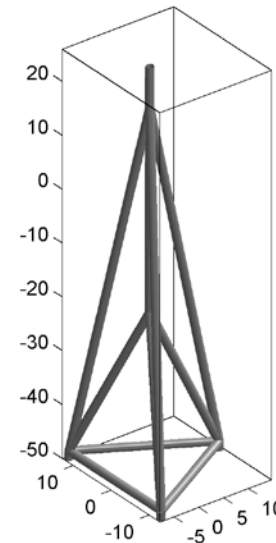
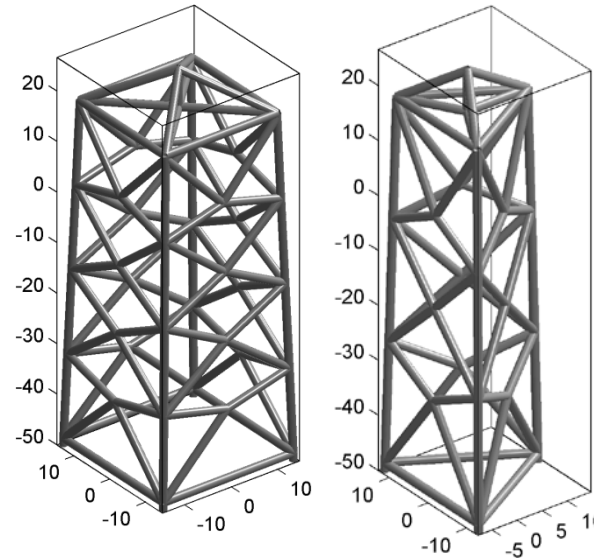
- Thrust peak shaving



JacketOpt

Topologies

- Classical four legged jackets
- Classical three legged jackets
- Pod-like structures (three or four legs)
- Full-lattice towers (three or four legs)
- Monopiles
- User defined structures



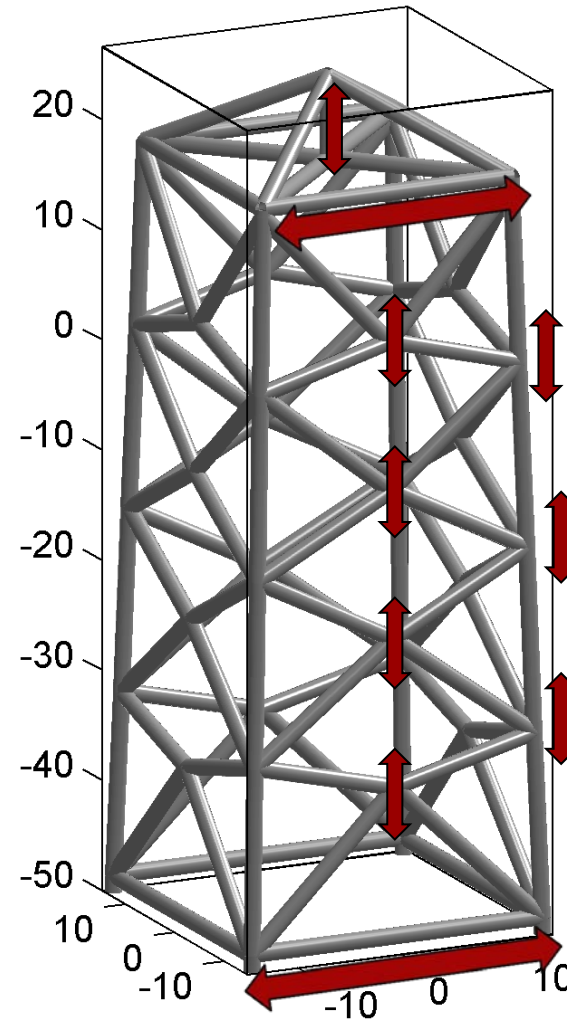
JacketOpt

Design variables (outer)

- Overall dimensions within bounds
- Placement of X-braces within bounds

Design variables (inner)

- Member diameters within bounds
- Member thickness within bounds



JacketOpt GUI

Jacket Optimization Module (Static Loads)

Outer problem definition

General data

Jacket height [m]: 76.00

Mud brace height [m]: 1.50

Water depth [m]: 50.00

Number of legs: 3

Number of brace levels: 4

Max finite element size [m]: 1.00

Tower inner radius [m]: 3.800

Variable linking: Symmetry+legs+braces

Structure type: Classical jacket

Variables

8.00 <= Half base width [m] <= 20.00

8.00 <= Half top width [m] <= 16.00

5.00 <= Transition height [m] <= 10.00

Inner problem definition

Objective function: Minimize mass

Constraints

☐ Local von Mises constraints (static)

Yield strength [MPa]: 355.00

Material factor: 1.15

☒ Frequency constraint(s)

0.27 <= First [Hz] <= 0.31

0.27 <= Second [Hz] <= 0.31

1.00 <= Third [Hz] <= 1.10

1.00 <= Fourth [Hz] <= 10.00

☐ Mass constraint

Mass [tonnes] <= 1000

Max top displ. [m] <= 2.00

30.00 <= D/t ratio <= 120.00

Design variables for legs

0.25 <= Inner radius [m] <= 1.50

0.02 <= Thickness [m] <= 0.12

Design variables for braces etc

0.10 <= Inner radius [m] <= 1.00

0.01 <= Thickness [m] <= 0.05

Design variables for transition jacket

0.25 <= Inner radius [m] <= 1.50

0.01 <= Thickness [m] <= 0.12

Solver options (outer problem)

Solver: GPS

Optimality tolerance: 1.0e-03

Feasibility tolerance: 1.0e-06

Max. iterations: 500

Max. function evals.: 500

Time limit [h]: 24

Verbosity: One line ...

Solver options (inner problem)

Solver: IPOPT

Optimality tolerance: 1.0e-03

Feasibility tolerance: 1.0e-05

Max. iterations: 500

Max. function evals.: 500

Verbosity: One line ...

Files

Mass file: JacketData\InnWindtowerOffshoreRamboltt.mass

Loads file: JacketData\InnWindtowerOffshoreRamboltt.loads

BC file: JacketData\InnWindtowerOffshoreRamboltt.bc

Tower geometry file: JacketData\InnWindtowerOffshoreRamboltt.geo

Tower sections file: JacketData\InnWindtowerOffshoreRamboltt.sec

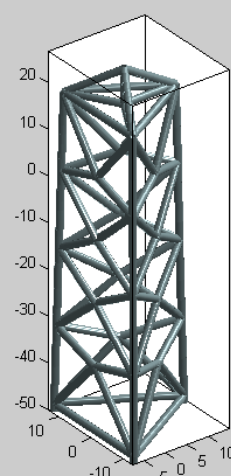
Tower dimensions file: JacketData\InnWindtowerOffshoreRamboltt.dim

Results files: JacketData\jacket_opt

Optimize

Export results

Figure 1



A 3D wireframe model of a jacket structure, showing a central vertical column with four legs extending outwards and bracing. The structure is plotted within a 3D coordinate system with axes ranging from -10 to 10 on the horizontal plane and -50 to 20 on the vertical axis.

A preliminary example for INNWIND.EU

DTU 10 MW reference turbine

- Hub height 119 m
- Rotor mass 229 tons
- Nacelle mass 446 tons
- Tower mass 505 tons

Four legs and four levels of X-braces

Minimum mass design

Max tower top displacement 2.25 m

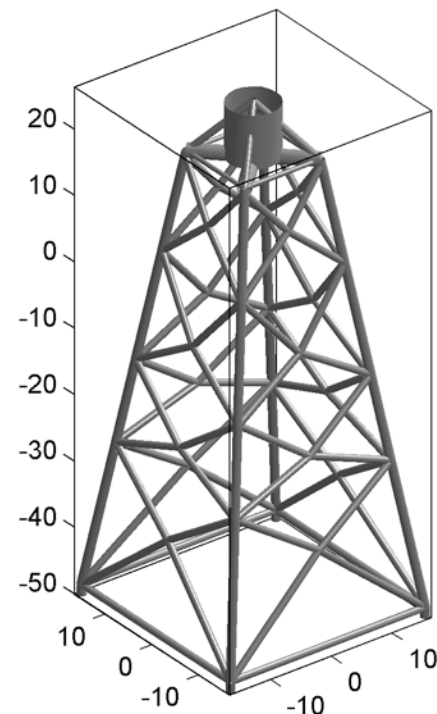
First and second frequency between 1P and 3P

Third and fourth frequency above 6P

Static loads only!

No fatigue constraints!

Best found design. Mass: 1.09151 [ktonnes].



A preliminary example for INNWIND.EU

DTU 10 MW reference turbine

- Hub height 119 m
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Four legs and three levels of X-braces

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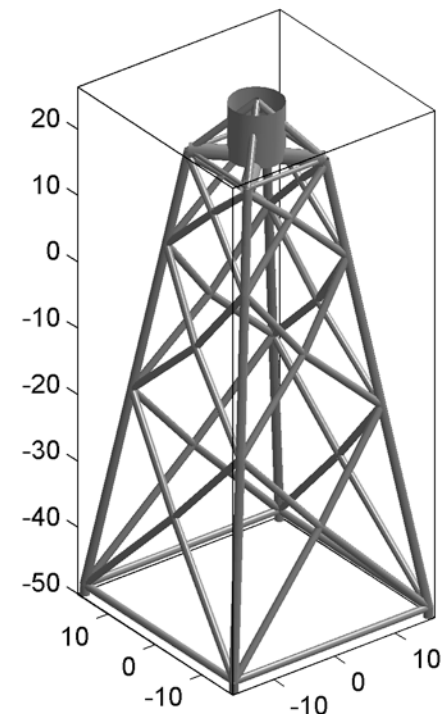
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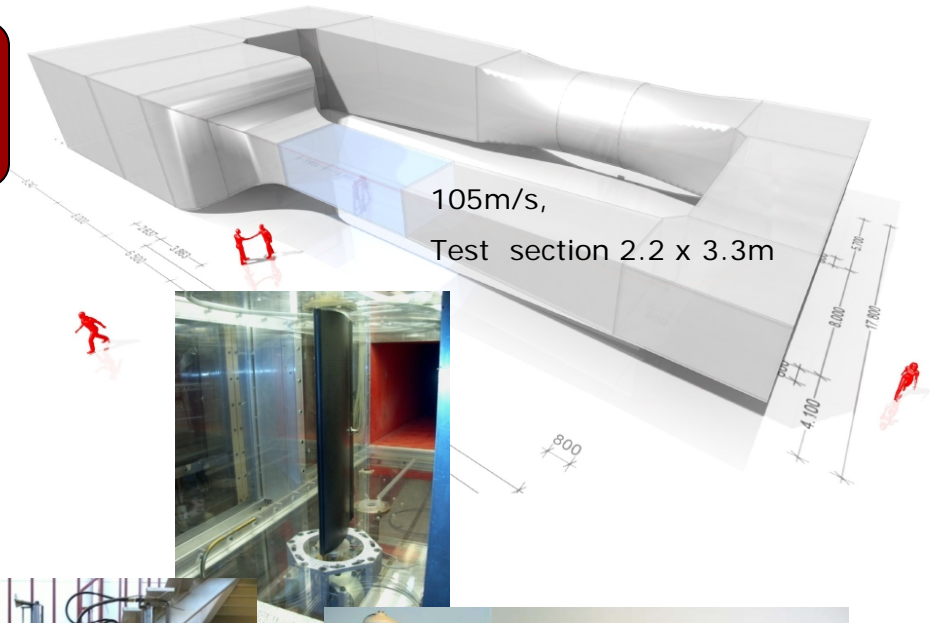
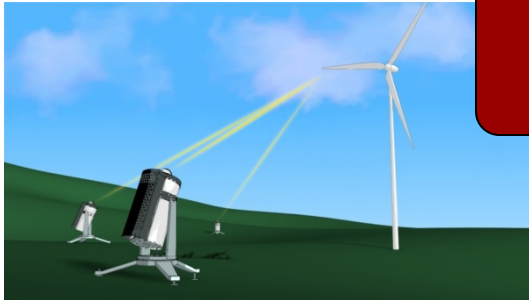
No fatigue constraints!

Best found design. Mass: 1.0419 [ktonnes].



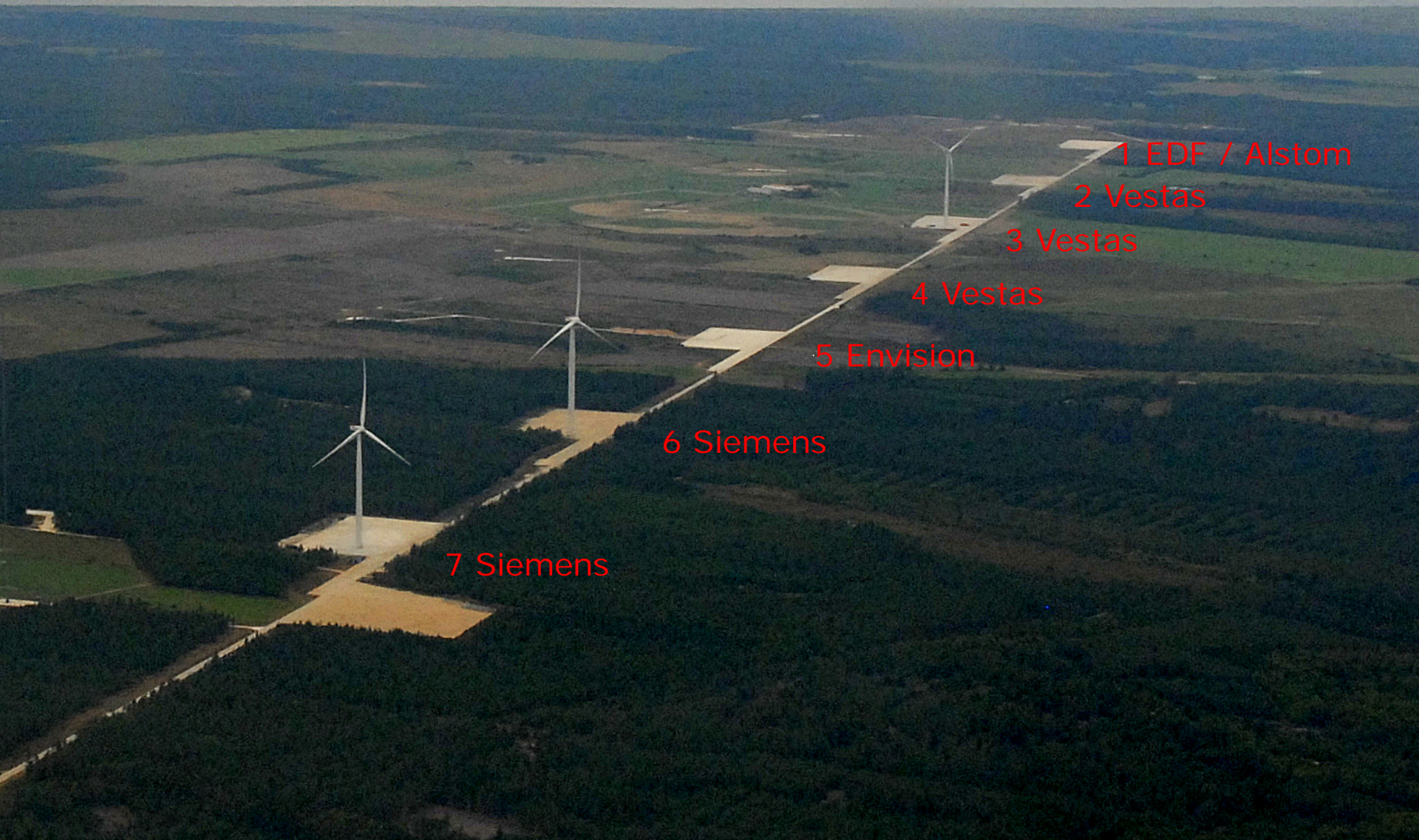
Validering og Test

F&U og test
faciliteter

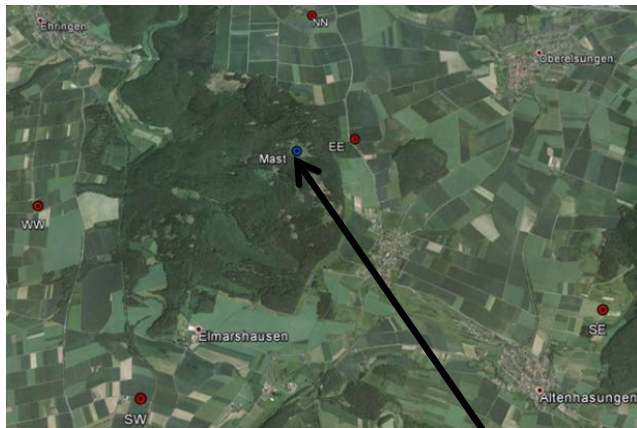


Østerild Test Centre – Prototype Wind Turbines

7 Wind Turbines – Max. 16 MW each – Max. height 250 m

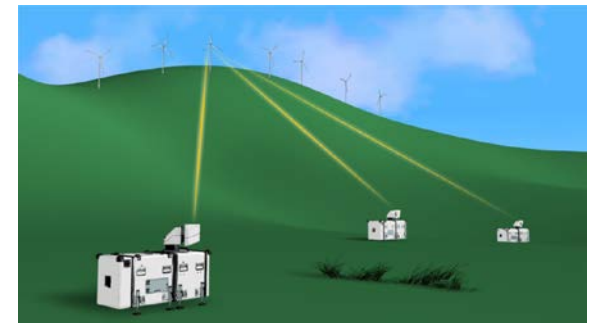


Long range windscanner – Kassel campaign



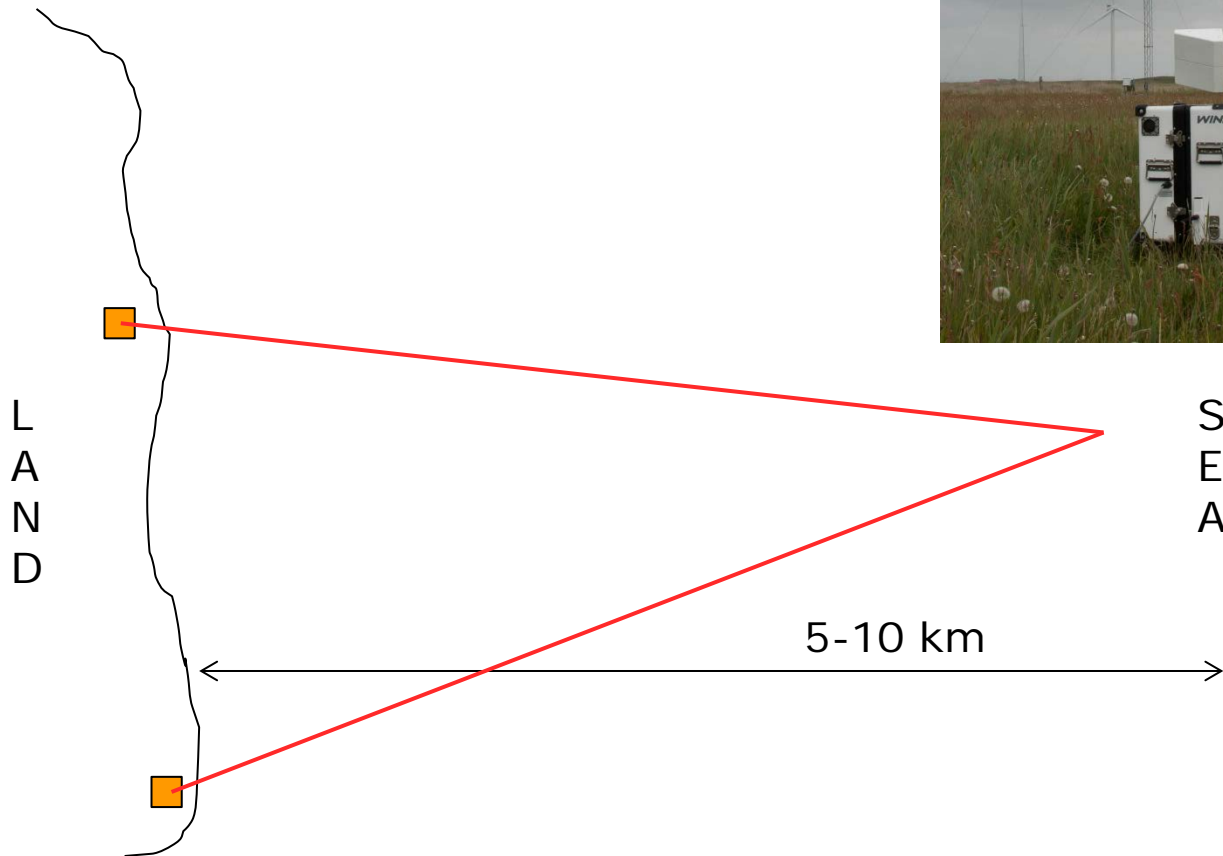
Metmast

- Measured for 6 weeks with 6 windscanners, full synchronisation over a 3G network
- Alignment accuracy of about 0.05° (1m over 1km)
- Excellent measurement results in scanning mode – within 1% accuracy at $> 3\text{km}$



Lidar ways of measuring the offshore resource

2. Windscanner(s) on the coast



An aerial photograph showing a long suspension bridge spanning a large body of water. In the foreground, several white offshore wind turbines are visible. The bridge has two large pylons and a long approach viaduct. The water is a deep blue, and the sky is clear. In the background, a coastal town and more wind turbines are visible on the horizon.

Spørgsmål